ZESZYTY NAUKOWE POLITECHNIKI ŚLĄSKIEJ 2011
Seria: TRANSPORT z. 73 Nr kol. 1861

Marcin STANIEK

THE CROSSROADS LIGHTS FUZZY CONTROLLER DEVELOPMENT PRINCIPLES IN VISSIM ENVIRONMENT

Summary. The study discusses the model of fuzzy controller used for traffic light system of traffic phase control with respect to formal requirements and traffic safety [1]. The assessment and comparison of traffic conditions were carried out for the following operating modes in traffic light systems: fuzzy logic, fixed-time and acyclic mode for traffic intensity data registered at real-life crossroads. The model for description of traffic phases based on a standard description of pua [2] data was presented. The VISSIM traffic simulation environment was presented, with a detailed description of control module.

METODA PROJEKTOWANIA ROZMYTEGO STEROWNIKA RUCHU DROGOWEGO W ŚRODOWISKU VISSIM

Streszczenie. W artykule opracowano model sterownika rozmytego sygnalizacji świetlnej dla sterowania fazowego przy zachowaniu wymagań formalnych i bezpieczeństwa ruchu [1]. Przeprowadzono ocenę i porównanie warunków ruchu dla programów pracy sygnalizacji świetlnej: rozmytego, stałoczasowego i acyklicznego dla natężeń ruchu z rzeczywistego skrzyżowania. Przedstawiono model opisu faz ruchu opierający się na standardzie opisu danych PUA [2]. Omówiono środowisko symulacyjne VISSIM ze szczegółowym opisem modułu sterowania.

1. INTRODUCTION

A variety of publications can be found in the related literature, where a number of traffic control methods have been discussed [3]-[13]. Some of these methods have been implemented and are currently used in many cities e.g.: CRONOS [3], SCOOT [4], UTOPIA [5], RHODES [6].

Other methods are of experimental character and have been only tested under simulation conditions or in selected crossroads. The most modern solutions concern application of artificial intelligence methods for control of road traffic [7], with particular focus on multi-agent systems [8], immunological systems [9], fuzzy logic [10], neural networks [11], genetic algorithms [12] and cellular automata [13].

Design and modernization of existing solutions for road traffic control is aimed at improvement of traffic capacity and safety on crossroads. The proposed solutions are verified as early as before implementation. The measures of effectiveness of control are checked in terms of meeting optimization criteria stipulated by the Minister of Infrastructure [1].

Assessment of the proposed solutions requires calculations of traffic capacity. Current version of Polish calculation method takes into consideration empirical data on the national scale, results of simulations and updating according to changes implemented in the methods used abroad [14].

Calculation procedure for accommodation and acyclic control has been used for verification of traffic capacity for the maximal program realized during periods of rush hours and momentary congestions [14]. It does not take into consideration the cases of the effect of traffic congestions at the outlet of a crossroad on its performance as well as accumulation areas in crossroads with central traffic island and wide division strip. In these cases it is preferred to make use of simulation models for assessment.

One of simulation software packages is VISSIM, dedicated for modelling individual traffic and public transportation. The software allows for analysis of conditions of traffic in consideration of such conditionings as configuration of lanes, structure of traffic types, traffic light systems and public transportation stops. Also, it provides a useful tool for assessment of different alternative solutions used for the measures of effectiveness. It is based on psychophysical model of driver's behaviour developed by WIEDEMANN (1974) [15].

VISSIM has been used for development, assessment and verification of control logic for optimization of traffic flow in road networks, analysis of traffic disturbances caused by e.g. low speeds and areas of traffic intersections. An advantage of VISSIM environments lies in facilitated comparison of alternative projects which include the crossroads with traffic lights, crossroads with road signs and huge multi-level traffic junctions.

2. ADVANCED ALGORITHMS OF ROAD TRAFFIC CONTROL

A fundamental aim of a controller in traffic light control system is to affect behaviour of the drivers and pedestrians through changes in light signals according to a set of rules defined in a control algorithm. Conventional theory of control makes use of mathematical models for determination of relationships of the system state and control signals in this system.

With classical approach, increase in complexity of a system causes extension in its mathematical description. Fuzzy logic control changes a complex mathematical model into a set of simple rules. Individual rules describe the elements of the system, whereas their interrelation into a reasoning system defines a demanded output signal.

The idea of use of fuzzy control in traffic light systems determines the algorithm of traffic control as an algorithm described on knowledge base coded in the form of rules. The knowledge base is developed through human experience and intuition and based on theoretical and practical understanding of the dynamics of the control plant. It requires specialized knowledge and experience in road traffic control.

An advantage of fuzzy logic consists in opportunities for using inaccurate and linguistic data as information useful for designing of the program of traffic light control.

3. FUZZY CONTROLLER FOR TRAFFIC LIGHT SYSTEMS

Cyclic program of traffic light control is a frequent solution used for control of traffic streams in crossroads. Traffic phases are activated by the vehicles which pass by certain detectors, ensuring traffic participants a required minimal duration of displaying green light signal. If the intensity of flow of vehicles reaches a particular level, the length of displaying green light is elongated in proportion to the number of vehicles, however not longer then a predefined maximal level.

In the case of lack of information from the other traffic participants, the active signal group in a traffic phase maintains the green light signal (passive green). At the moment of information, the signal is switched. In the case of lack of traffic demand for all signal groups, the controller displays red light signal for the whole crossroads.

The algorithm of fuzzy logic control for road traffic system proposed in the study uses the data from the traffic detection system. The detectors in the model of a crossroads were defined at each inlet to the crossroads at the line of conditional stop (presence detector). This location of detectors allows for determination of the number of vehicles which approach the line of conditional stop within the time of another 6-8 seconds and the number of vehicles queued before the stop line.

The task of fuzzy controller for road traffic light control is to initiate changes of traffic phases (initiate inter-phase signal sequence) and extend the duration of green light signal. Selection is made based on the data from the detection system combined with information from fuzzy reasoning.

Fig. 1 presents the model of crossroads with traffic light system. The signal groups and road traffic detectors were marked.

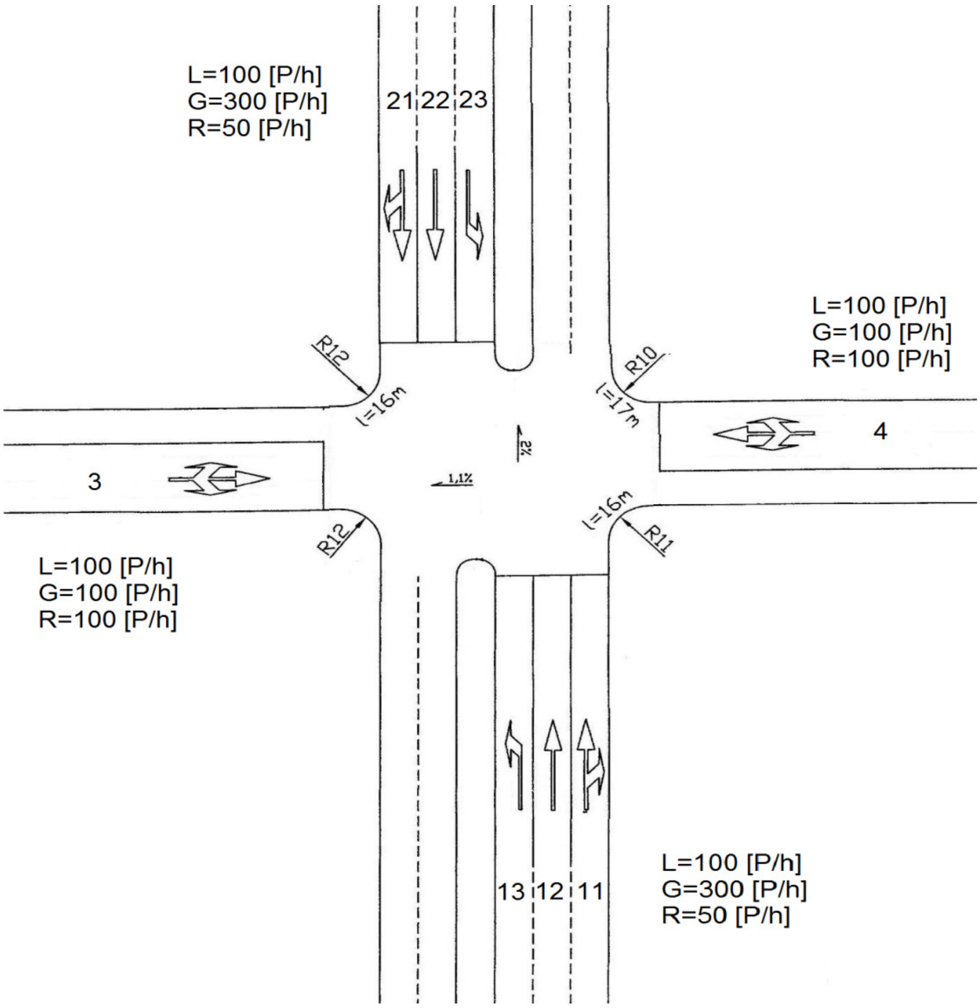

Fig. 1. Model of crossroads with traffic light system

Rys. 1. Model skrzyżowania z sygnalizacją świetlną

Two input variables based on fuzzy logic principles were defined in control algorithm developed in the study:

- Z – number of vehicles approaching the crossroads,
- K – number of queuing vehicles.

The response of the fuzzy logics system is an output variable W which defines extension of green signal duration. Extension of time at zero level means a change of traffic phase in the program of traffic light control. Fuzzy control for traffic light system is presented in Fig. 2.

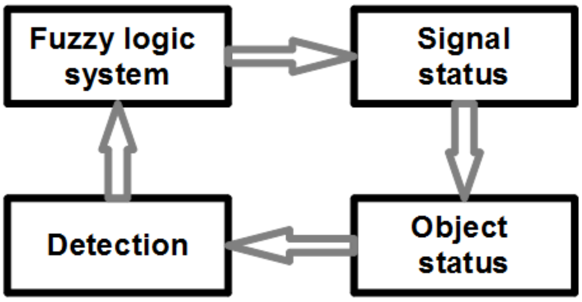

Fig. 2. Fuzzy control for controlling traffic light system.
Rys. 2. System rozmytego sterowania sygnalizacją.

Fuzzy logic rules of initiation of phase change and extension of duration of green light signal are presented below.

if Z = zero then initiate inter-phase transition.
if Z is small and K is small then W is short or
if Z is middle and K is any queue then W is middle or
if Z is big and K is any queue then W is large.

According to formal requirements for signalisation programs [1], reasoning system starts operating after sending a minimal duration of green light signal.

Membership function of the number of vehicles which approach the crossroads and the number of queuing vehicles are presented in Fig. 3 and Fig. 4, respectively.

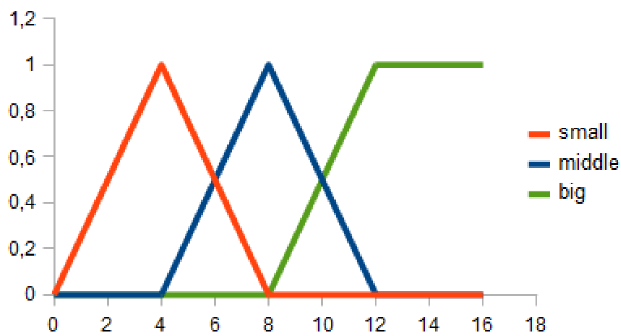

Fig. 3. Membership function for the number of vehicles approaching a crossroads
Rys. 3. Funkcja przynależności liczby pojazdów zbliżających się do skrzyżowania

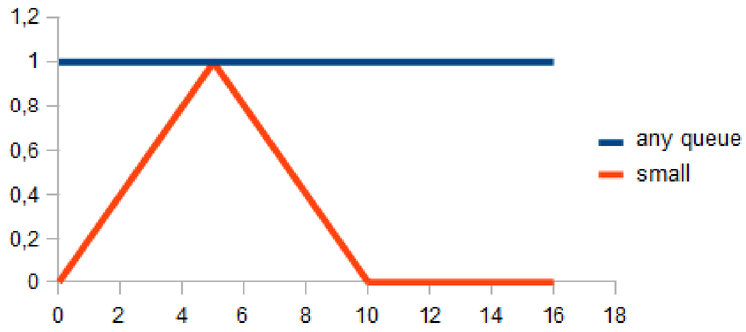

Fig. 4. Membership function for the number of queuing vehicles
Rys. 4. Funkcja przynależności liczby pojazdów oczekujących w kolejce

Response of the fuzzy reasoning system means a change in traffic phase or extension of green signal duration. The output information requires transformation of fuzzy values into discrete values. Centroid method [] was employed for the process of defuzzification.

Extension of green light signal was defined by the membership function presented in Fig. 5.

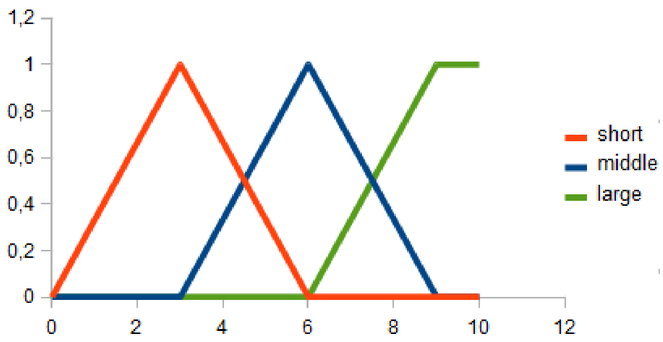

Fig. 5. Membership function for extension of green light signal
Rys. 5. Funkcja przynależności wydłużenia sygnału światła zielonego

4. Implementation of Traffic Control Algorithms

VISSIM environment was used for modelling, simulation and assessment of the proposed fuzzy road traffic controller. The environment allows for determination of parameters significant for optimization of control programs such as: crossing duration, delay time, number of queuing vehicles.

A model of traffic control according to inter-phase transitions developed by the author was employed during implementation of fuzzy controller for traffic light system. It ensures safe method of switching from one traffic phase into another and meeting formal requirements as well as road traffic safety stipulated by the Minister of Infrastructure [1].

In inter-phase transitions, there are a change in traffic light signal, displayed by signal groups from the signal of permission into the signal of prohibition for entry to the crossroads and the opposite pattern. For a part of signalisation groups, a change in light signal might not occur. The inter-phase transition developed by the designer might be performed for the whole or a part of the crossroads.

An example of inter-phase transitions is presented in Fig. 6. Signalisation groups K6, K7 receive green light signal. Sending the red light signal initiates for the group K4, K5. No switching points are defined for the group K1, K2, K3 and thus the change in signal does not occur.

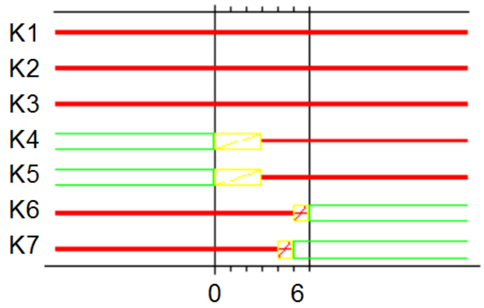

Fig. 6. Graphical illustration of inter-phase transition
Rys. 6. Graficzna ilustracja przejścia międzyfazowego

A collection of inter-phase transitions with maintaining of minimal duration of green light creates a control program for traffic light system. Construction of signalisation program calls for obtaining a signal of green light within the timeframe which does not exceed 120 seconds for signalisation groups which are waiting for permission for traffic in acyclic program.

The model of inter-phase transitions proposed by the designer of traffic control algorithm and the model proposed in the study determine a program of traffic light control. The structure of the program using the VISSIM simulation environment is subject to optimization requirements of adaptation of signalisation programs to variable traffic conditions in order to obtain possibly higher effectiveness of traffic light system.

The model of inter-phase transitions developed in the study allows for adaptation of the program of traffic light control to traffic conditions in the crossroads. Depending on the state of signals from detection system, it is possible to switch traffic phases and define their duration.

A structure of the program for traffic light control based on inter-phase transitions meets all formal requirements and traffic safety requirements [1]. It allows for easy creation of a program of traffic light control without the necessity of verification of traffic safety requirements in the crossroads.

5. Comparison of the Proposed Solutions

A program of traffic light control for fuzzy controller was compared with the fixed-time cyclic program and the acyclic program. Fixed-time program does not take into consideration the information from detection system.

Program of operation of traffic lights for fixed-time version is presented in Fig. 7.

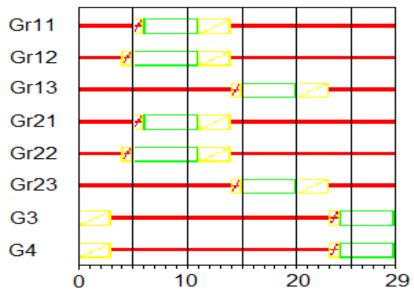

Fig. 7. Fixed-time program for traffic light system
Rys. 7. Program stałoczasowy sygnalizacji świetlne

Algorithm of control for the acyclic program allows for changes in traffic phases depending on the state of the system of detection. Possible options for inter-phase transitions are presented in the diagram in Fig. 8.

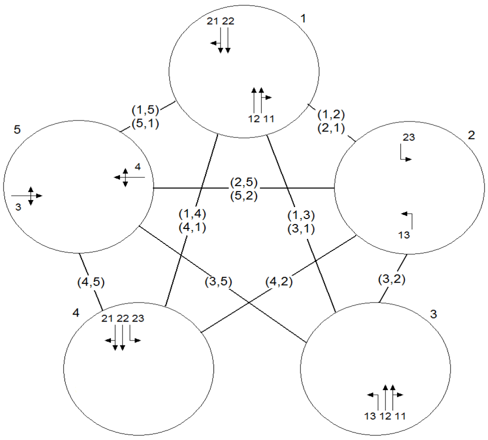

Fig. 8. Diagram of inter-phase transitions
Rys. 8. Diagram przejść miedzyfazowych

Table 1 contains the elements of measure of assessment of conditions for three control algorithms in the modelled crossroads.

Table 1

The measure of assessment of conditions for control algorithms

	Fuzzy controller	Fixed-time program	Acyclic program
The total time of vehicle crossing the crossroad [h]	18,58	20,85	22,06
The number of stops [/]	1092	1102	1181
The number of stops [/]	13,54	14,15	14,89

Assessment of traffic conditions in the modelled crossroads for three types of crossroads reveals that total time of vehicle crossing the crossroads is the shortest for fuzzy control. The number of stops in the case of fuzzy control and fixed-time control is similar. Mean delay is lower for fuzzy control compared to the other types of control.

6. Conclusions

This study compares three types of control programs: fixed-time, acyclic and fuzzy control. The first two types are standard algorithms of traffic control used in the crossroads. Fuzzy control is at the stage of scientific research and information about this control is contained in the literature [1].

Fixed-time control does not require application of the system of detection of vehicle and pedestrian flow. Program for operation of traffic light control does not take into consideration variability of traffic conditions and momentary traffic disturbances in the crossroads.

Acyclic control is based on the data from the system of traffic detection. It adapts the program of traffic light control to the conditions of the crossroads. In the case of erratic interpretation of data from detectors or failure of the detection system, the program operates non-optimally or it switches to fixed-time operation mode.

Similarly to acyclic control, fuzzy control proposed by the author of the present study makes use of information from the system of detection of vehicle and pedestrian traffic. This type of control does not require high frequency of decisions on changes in light signals, contrary to the classic acyclic control. Information about extension of green light signal constitutes a timeframe where traffic controller does not make another decision.

The model of inter-phase transitions proposed by the author allows for safe method of switching from one traffic phase to another. Also, it provides an easy manner of structuring an operation program for traffic light system. It allows for modelling and implementation of advanced algorithms of traffic control based on artificial intelligence [7], multi-agent systems [8], immunological systems [9], fuzzy logic [10], neural networks [11], genetic algorithms [12] cellular automation [13].

Application of VISSIM environment for simulation of road traffic allowed for development, assessment and verification of control logic. The solution of fuzzy logic proposed for traffic light system enables optimization for variable traffic conditions in the road. A modification of the membership function for vehicles approaching the crossroads and the membership function for vehicles queued was made in order to obtain possibly best results of assessment of effectiveness of control.

The use of VISSIM environment has allowed for easy comparison of alternative projects including different types of control of traffic light system.

Bibliography

1. Rozporządzenie Ministra Infrastruktury z dnia 3 lipca 2003 roku w sprawie szczegółowych warunków technicznych dla znaków i sygnałów drogowych oraz urządzeń bezpieczeństwa ruchu drogowego i warunków ich umieszczania na drogach. Dz. U. Nr 220 z dnia 23 grudnia 2003r., poz. 2181.
2. Crossig. User Manual Version 3.70, PTV AG Stumpfstr.1, Karlsruhe, Germany 2007.
3. Boillot F., Midenet S., Pierrelée J.C.: The real-time urban traffic control system CRONOS: Algorithm and Experiments. Transportation Research, Part C, Vol. 14, No. 1, Elsevier 2006.
4. Bretherton R. D., Bodger M., Baber N.: SCOOT – Managing Congestion Communications and Control. Proc. of ITS World Congress, San Francisco 2005.
5. Mauro V., DiTaranto, C.: UTOPIA. Control, Computers, Communications in Transportation: Selected Papers from the IFAC Symposium, Pergamon Press 1990.

6. Mirchandani P.B., Head K. L.: RHODES: A Real- Time Traffic Signal Control System: Architecture, Algorithms and Analysis. Transportation Research, Part C, Vol. 9, No. 6, Elsevier 2001.
7. Liu Z.: A Survey of Intelligence Methods in Urban Traffic Signal Control. Int. J. of Computer Science and Network Security, Vol. 7, No. 7, 2007.
8. Chen X., Yang Z.-S., Wang H.-Y.: A Multi-agent Urban Traffic Control System Cooperated with Dynamic Route Guidance. Proc. of the Fifth Int. Conf. on Machine Learning and Cybernetics, IEEE, Dalian 2006.
9. Jia L., Yang L., Kong Q., Lin S.: Study of Artificial Immune Clustering Algorithm and Its Applications to Urban Traffic Control. Int. J. of Information Technology, Vol. 12, No. 3, WASET, 2006.
10. Niittymäki J. P.: Fuzzy Traffic Signal Control. Applied Optimization. Transportation Planning. Kluwer Academic Publishers, New York 2002.
11. Teodorović D., Varadarajanl V., Popović J., Chinnaswamy M., Ramaraj S.: Dynamic programming neural network real-time traffic adaptive signal control algorithm. Annals of Operations Research, Vol. 143, No. 1, Springer Netherlands 2006.
12. Turky A. M., Ahmad M. S., Yusoff M. Z. M., Hammad, B. T.: Using Genetic Algorithm for Traffic Light Control System with a Pedestrian Crossing. RSKT 2009, LNCS 5589, Springer-Verlag Berlin Heidelberg 2009.
13. Wie J., Wang A. Du N.: Study of self-organizing control of traffic signals in an urban network based on cellular automata. IEEE Trans. on Vehicular Technology, Vol. 54, No. 2, IEEE 2005.
14. Tracz M., i in.: Metoda obliczania przepustowości skrzyżowań z sygnalizacją świetlną, Katedra Budowy Dróg i Inżynieri Ruchu, Politechnika Krakowska, Kraków 2004.
15. Datka S., Suchorzewski W., Tracz M.: Inżynieria ruchu, WKŁ, Warszawa 1999.

Recenzent: Prof. dr hab. inż. Ryszard Tadeusiewicz